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FLIR IMAGE ENHANCEMENT BY AUTOMATIC LOW FREQUENCY GAIN LIMITING--ETC(U)
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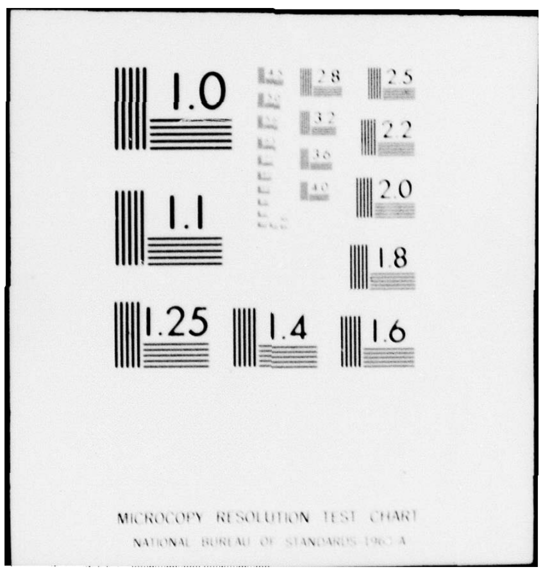
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(6) FLIR IMAGE ENHANCEMENT BY AUTOMATIC LOW FREQUENCY GAIN LIMITING. (U)

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I. INTRODUCTION

An inherent problem with existing Military FLIR Common Module systems[1] is that the dynamic range of the thermal scenes far exceeds that of the system display. Current displays used in FLIR systems have a dynamic range of approximately 30 db (32:1) and typical infrared scenes can be several orders of magnitude greater. A common example being the terrain-sky horizon which an Airborne FLIR encounters when the helicopter or aircraft makes a steep bank. In this scenario some of the channels in the vertical array of detectors will be viewing both the hot terrain and cold sky. This scene dynamic range can be as high as 500 to 1, or 54 db, with a temperature difference, ΔT of 100°C and the noise equivalent differential temperature (NEΔT) of 0.2°C. The display of the channels will be such that the terrain saturates to white and the sky is suppressed to black, assuming that the system polarity switch is in the white/hot mode. Now if the operator attempts to reduce the gain of the system, such that both areas are within the dynamic range of the display, he is unable to perceive detail in both regions due to a lack of contrast. At this moment the operator may adjust the brightness level and maintain the contrast high enough to perceive either the terrain or the sky detail but not both simultaneously. In addition, the operator has to contantly adjust both the brightness and the contrast controls for the various types of scenarios encountered in flight and if the operator is the pilot, this reduces his ability to navigate. To accommodate approximately 60 db of scene information onto a 30 db display a large degree of signal compression is required. Classical methods of automatic gain control and logarithmic compression techniques are unable to preserve the detail signal over such a large

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dynamic range and provide the fast response time required in missile tracking applications. This paper describes an electronic approach to solve this problem called "Automatic Low Frequency Gain Limiting"[2]. This circuit limits the amplitude of the signal pedestal and enhances the high frequency scene detail. Thus it expands the perceivable scene dynamic range and provides the fast response time required by many military applications.

II. PRINCIPLE OF AUTOMATIC LOW FREQUENCY GAIN LIMITING

A. Principle of Operation

The Automatic Low Frequency Gain Limiting circuit operates in two modes depending on the input signal level. When the signal amplitude is within the prescribed detection levels, it is fed directly to the output. However, as the signal amplitude either exceeds the white detection level or is below the black detection level, it compresses the pedestal, the average value of the local background, and preserves detail, the temperature variation of interest in all parts of the scene. Since this approach essentially preserves most of the high frequency detail and automatically limits the average value of the local background, which mainly consists of low frequency components, it is called "Automatic Low Frequency Gain Limiting (ALFGL)."

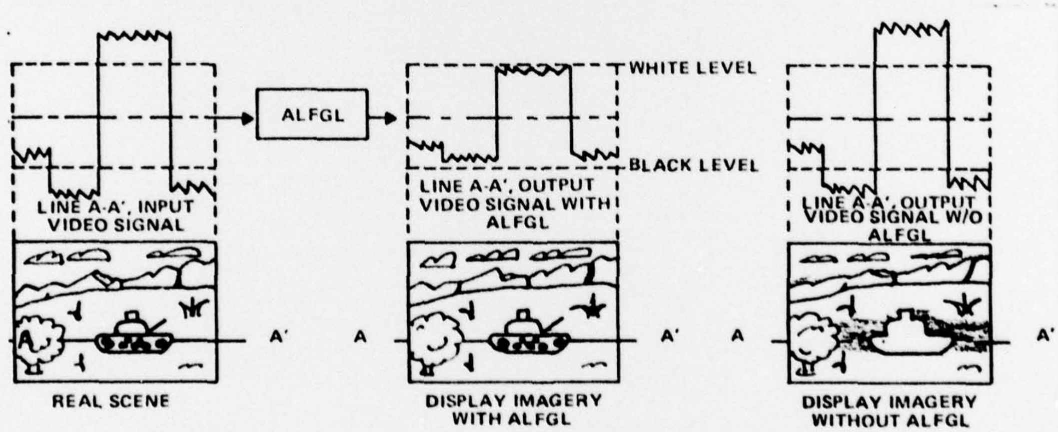

Fig. 1A.
System with ALFGL

Fig. 1B.
System without ALFGL

Figure 1A exhibits the display imagery and the video signals at line A-A' of the system with ALFGL. In this case: (i) the tree signal is within the detection levels, thus, it is fed directly to the

output, (ii) the signal level of the hot tank exceeds the white detection level, therefore, the pedestal is compressed, yet the tank detail is preserved and (iii) the terrain signal levels on both sides of the tank are below the black detection level, where the terrain pedestals are clipped and the detail signals are preserved. In Figure 1B the system does not have ALFGL. In this case, the tank signal saturates to the display white level and the cold terrain signal is suppressed below the display black level. Therefore, the scene detail is lost in the terrain area on both sides of the tank and is also lost in the local horizon.

B. Signal Transfer Characteristic

The ALFGL signal transfer characteristic is shown in Figure 2. In the nonlimited condition, i.e., the input signal is within $-e_1$ and e_1, both pedestal and detail signal operate in the linear region A' O A. When the input pedestal exceeds e_1, the output

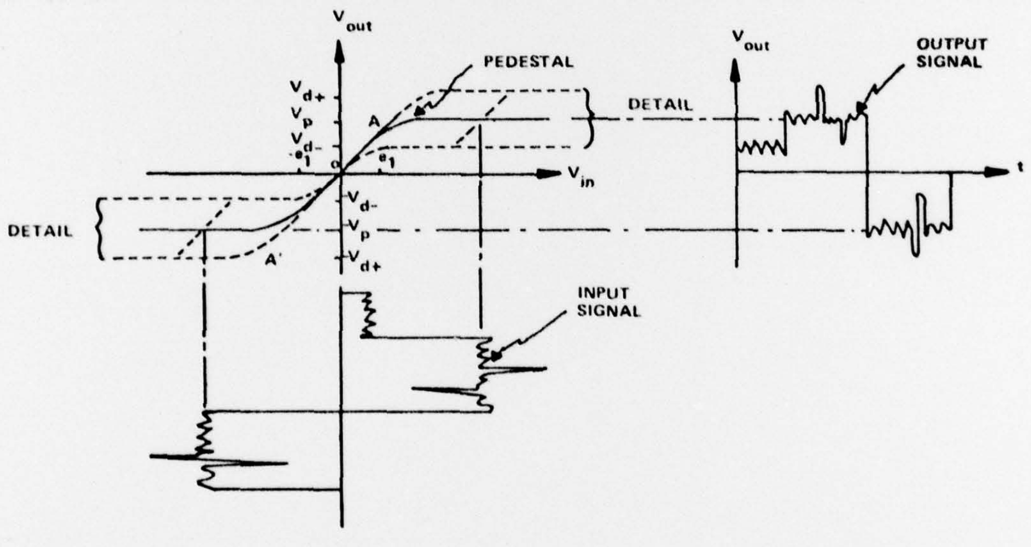

Fig. 2. Signal transfer characteristics

of the pedestal is limited to V_p, the detail signal is superimposed on this limited pedestal and operates within the limited range of V_{d+} to V_{d-}. Similarly, when the input pedestal is more negative than $-e_1$, it is limited to $-V_p$ and the detail signals operate within the limited range of $-V_{d+}$ to $-V_{d-}$.

C. Frequency Response

The frequency response of the ALFGL is shown in Figure 3.

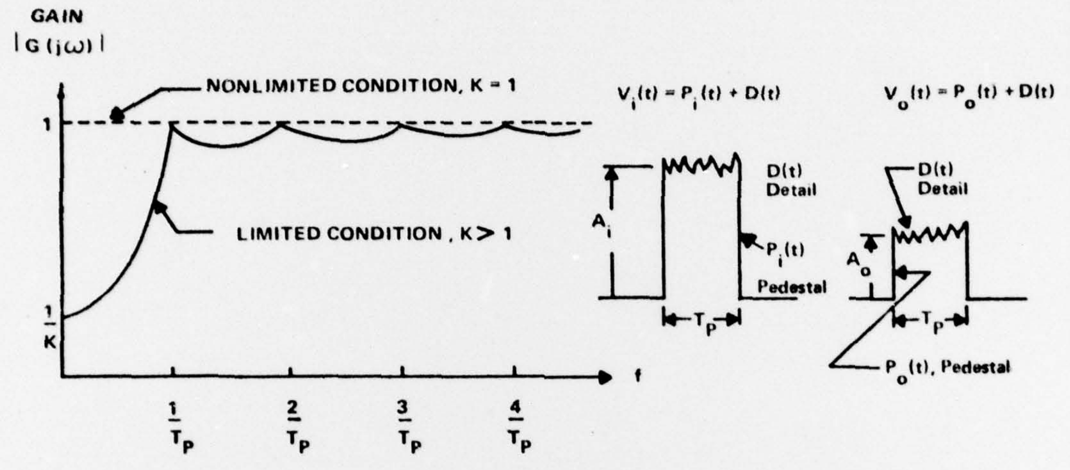

Fig. 3. Frequency response of ALFGL

Here we assume that the input signal, $V_i(t)$ is the sum of the pedestal, $P_i(t)$ and its detail, $D(t)$. The width of the pedestal is T_p. Similarly, the output signal, $V_o(t)$, is the sum of the limited pedestal, $P_o(t)$ and its detail, $D(t)$, the pedestal width is T_p.

If we take the Fourier transform of both input and output signals, then the transfer function is:

$$G(j\omega) = \frac{V_o(j\omega)}{V_i(j\omega)} = \frac{P_o(j\omega) + D(j\omega)}{P_i(j\omega) + D(j\omega)} = \frac{1 + \dfrac{D(j\omega)}{P_o(j\omega)}}{K + \dfrac{D(j\omega)}{P_o(j\omega)}} \tag{1}$$

$$\text{where:} \quad K = \frac{P_i(j\omega)}{P_o(j\omega)} = \frac{A_i}{A_o} \quad \begin{array}{l} >1, \text{ limited condition} \\ =1, \text{ nonlimited condition} \end{array} \tag{2}$$

$$\text{and} \quad P_o(j\omega) = A_o T_p \frac{\sin \omega T_p/2}{\omega T_p/2} \tag{3}$$

If we assume that the detail is much smaller than the output pedestal, then by inspection of equations (1) through (3) we have:

(i) $|G(j\omega)| \simeq \frac{1}{K}$ at $f = 0$

(ii) $|G(j\omega)| \approx 1$ at $f = \frac{n}{T}$ where: $n = 1, 2, 3, -, -,$

(iii) Attenuation is more dominant in the low frequency.

The approximate frequency response of the ALFGL in the limited condition is shown in the solid curve of Figure 3. In the nonlimited condition, where $K = 1$ and the $|G(j\omega)| = 1$ for all values of f. This is shown in the dotted line of the same figure.

III. ALFGL IMPLEMENTATION

Figure 4 depicts the block diagram of the ALFGL and its position in the common module video chain. The advantages of inserting

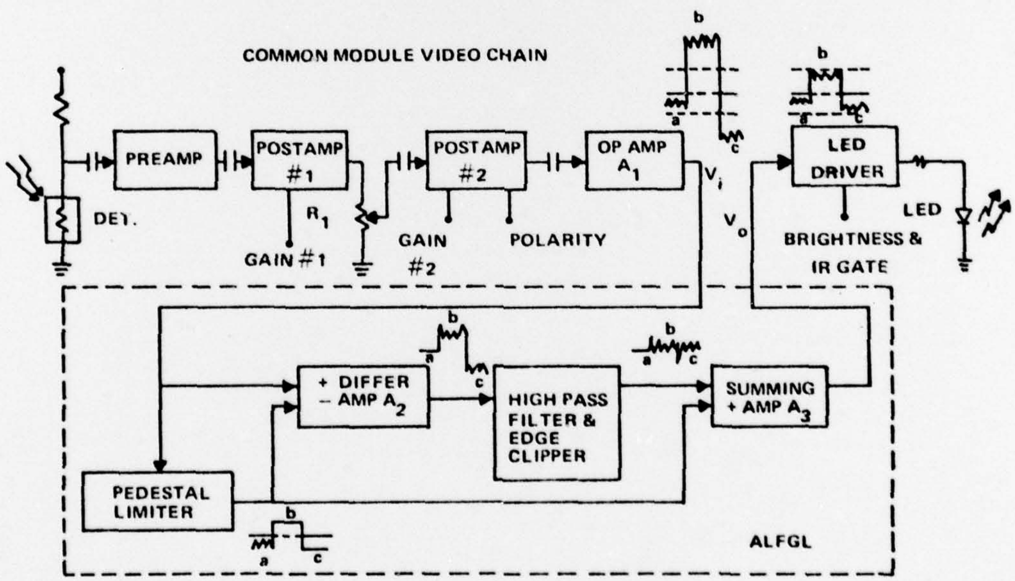

Fig. 4. ALFGL block diagram

ALFGL before the LED driver are: (i) it reduces the DC level shifting since video signals are directly coupled from the ALFGL to the display, (ii) semiconductor diodes can be selected for both black and white levels of detection since the signal amplitude is 0.5 to 1.5 volts, (iii) the system gain control function precedes the ALFGL circuit and thereby a change in the gain control setting will not effect the pedestal limiting level. This assures that the output signals are always within the dynamic range of the display and (iv) for remote view FLIRs, dynamic range expansion is not limited by the dark current of either the CCD image buffer or vidicon tube.

To analyze the operation of the ALFGL circuit consider input signals at three different signal levels: "a", "b" and "c". Assume that: level "a" is within the display dynamic range, level "b" exceeds the black detection level (it is inverted because the LED driver has a negative gain), and level "c" exceeds the white detection level.

(i) When an input signal of level "a" is fed into the ALFGL circuit, it passes through the pedestal limiter without attenuation and is directly fed to the lower input side of the summing amplifier, A_3. The signals at both inputs of the differential amplifier, A_2, are identical. Therefore, the differential amplifier output voltage is zero as is the upper side input of the summing amplifier, A_3. Consequently, the output of the summing amplifier is the lower side input signal, which is the same signal fed into the ALFGL circuit.

(ii) When the input signal level "b" is fed into the ALFGL circuit, the pedestal limiter clips the signal amplitude to the black limiting level. Then, it is directly fed into the lower input side of the summing amplifier, A_3. The output of the differential amplifier, A_2, contains both the detail and a reduced amplitude pedestal; the latter is then removed using a high pass filter and edge clipper to limit leading and trailing edge of the spikes. Thus, the output of the summing amplifier, A_3, is the sum of the input detail and the black level limited pedestal.

(iii) When the input signal level "c" is fed into the ALFGL circuit, the circuit is similar to case (ii) except that the pedestal limiter clips the signal to the white limiting level and the output of the summing amplifier, A_3, is then the sum of the detail and the white level limited pedestal.

Figure 5 shows the ALFGL schematic diagram where the operational amplifier A_1 is provided for dynamic range expansion. This avoids the presaturation of the post amplifier #2, which has an output

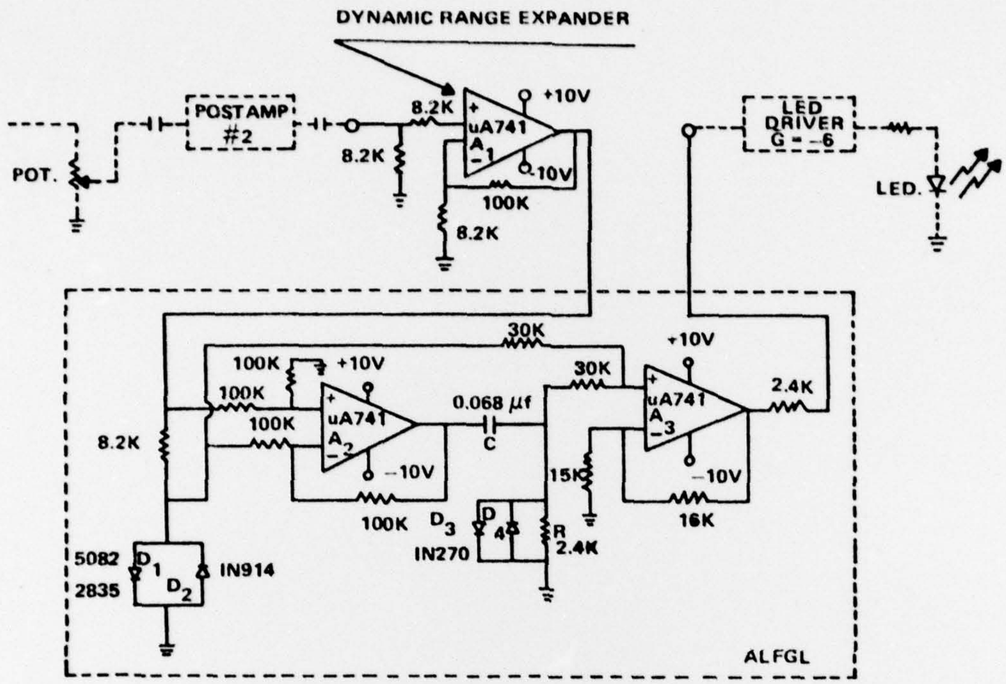

Fig. 5. ALFGL schematic diagram

voltage swing of 1.5 volts peak-to-peak. This is achieved by scaling down the resistor pot and compensates the attenuated gain by the operational amplifier A_1 which has a large output voltage swing. Diode D_1 is a black level detector which has a threshold voltage of 0.34 volt and diode D_2 is a white level detector with a threshold voltage of 0.5 volt. Amplifier A_2 is a differential amplifier, and the capacitor C and resistor R constitute a high pass filter for the detail signal path. Diodes D_3 and D_4 clip the high peak leading and trailing edges. Amplifier A_3 is a summing amplifier, which sums the detail signal across the resistor R and the pedestal across the diodes D_1 and D_2. The output of the amplifier A_3 is fed to the LED driver, which has a gain of -6.

IV. PERFORMANCE DATA

A. Voltage Waveforms

Typical voltage waveforms at the corresponding nodes of the ALFGL circuit are depicted in Figure 6 where the input signal is comprised of a 2 volts, 1.5 milliseconds wide pedestal and a 0.3 volts

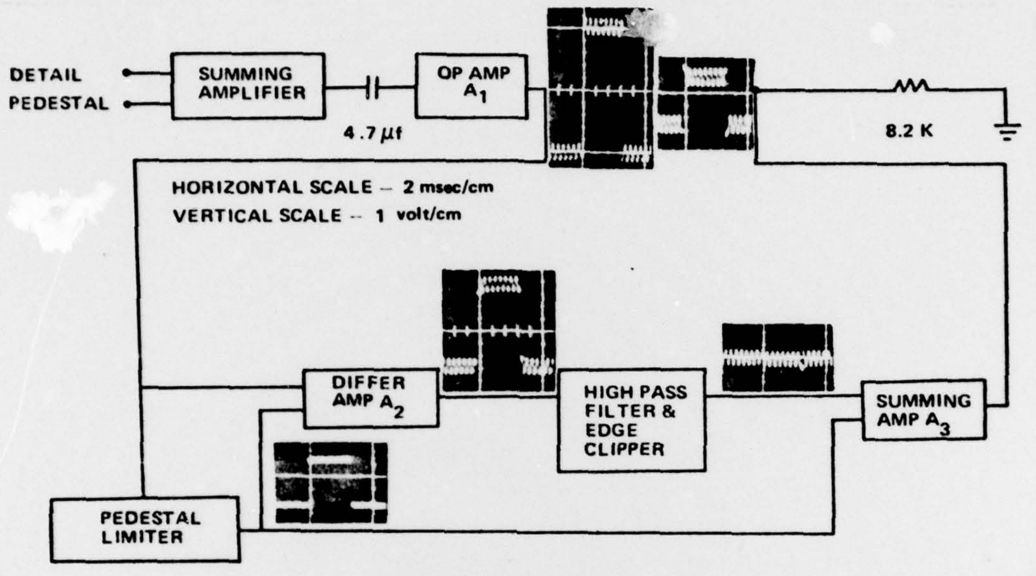

Fig. 6. Voltage waveforms

peak-to-peak 6 KHz sine wave. The signals which exceed either +0.35 or -0.5 volts are clipped off by the pedestal limiter and the signal which is lost at the pedestal limiter appears at the output of the differential amplifier, A_2. A high pass filter and edge clipper remove the remainder of the pedestal and clip the leading and trailing edge of the spikes. Thus the output of the high pass filter and clipper is the detail signal which was lost at the pedestal limiter. Consequently, the summing amplifier, A_3, simultaneously adds the same input detail signal and limited pedestal.

B. Dynamic Range Expansion

Amplifier A_1 in Figure 5 has a large output voltage swing of 17 volts peak-to-peak when biased with ± 10 volts. Since one volt peak-to-peak to the input of the LED driver will saturate the display the dynamic range expansion contributed by the ALFGL is 17/1 volts/volt or approximately 25 db. This allows the systems operator to maximize the gain of the system and enhance scene detail without saturating the display.

C. Minimum Resolvable Temperature (MRT)

Figure 7 depicts the system MRT, with and without ALFGL. Test results indicate that no degradation of MRT occurs with ALFGL circuitry in the system. This is logical since MRT is measured with a low signal level below the detection levels of the ALFGL circuit and is therefore fed directly to the output. Therefore, MRT should not be effected by ALFGL.

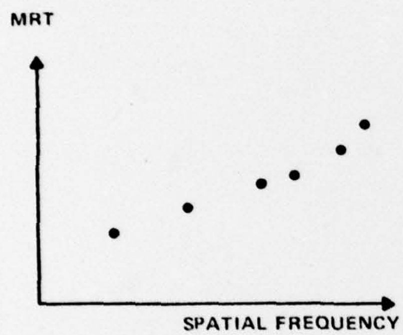

Fig. 7. Minimum Resolvable Temperature with and without ALFGL

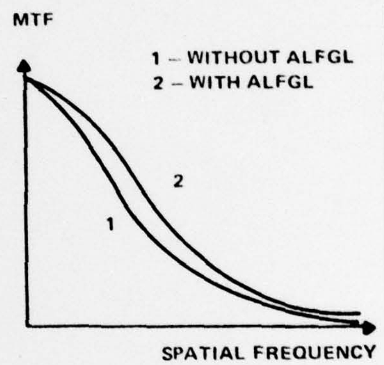

Fig. 8. Modulation Transfer Functions

D. Modulation Transfer Function (MTF)

Figure 8 shows how the system MTF is boosted when ALFGL is employed. This occurs because during the MTF measurement the signal amplitude generally exceeds the detection level of the ALFGL circuit. This results in boosting since the low frequency components are attenuated more than the high frequency components.

E. Narcissus Effect and 1/f Noise

The Narcissus effect, i.e., a dark image that appears in the center area of a display due to the detectors sensing their own cold surfaces relative to their warm surrounding[3] and 1/f noise are substantially reduced by the ALFGL circuits. This occurs since both the narcissus effect and 1/f noise are essentially low frequency components which are limited by the ALFGL circuitry.

V. FIELD TEST RESULTS

A. Combat Vehicle Applications

In a combat vehicie battlefield environment, targets are frequently encountered in the vicinity of large fires and burning vehicles. For a FLIR to perceive target detail in this scenario it must have a large dynamic range. Fire tests were conducted in the field to determine the capability of the ALFGL circuitry in this extreme thermal scenario. The tests indicate that the 25 db of dynamic range expansion of the ALFGL FLIR is barely adequate.

B. Airborne Applications

Helicopter flight tests were conducted with a FLIR system in which half the FLIR channels contained ALFGL circuitry and the other half contained standard common module electronics. The results of these tests clearly indicate that the serious image streaking problem (loss of scene detail) in the vicinity of the horizon is eliminated. This is shown in Figure 9 where the top half of the scene illustrates the imagery of the ALFGL circuits. Figure 10 shows the IR imagery of a tower and illustrates how the upper tower details are enhanced by the ALFGL circuitry.

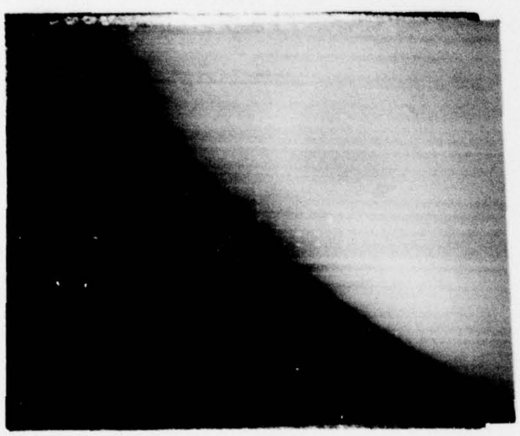

Fig. 9. Horizon.
Upper half with ALFGL
Lower half without ALFGL

Fig. 10. Tower.
Upper half with ALFGL
Lower half without ALFGL

C. Missile Tracking Applications

Another problem with Common Module FLIR systems was their inability to perceive targets in the vicinity of the rocket plume. A static firing test was conducted with an ALFGL modified FLIR, where simulated targets were placed in the vicinity of the rocket plume. Figure 11 shows the results of this test and indicates that the simulated targets can be observed during the rocket firing.

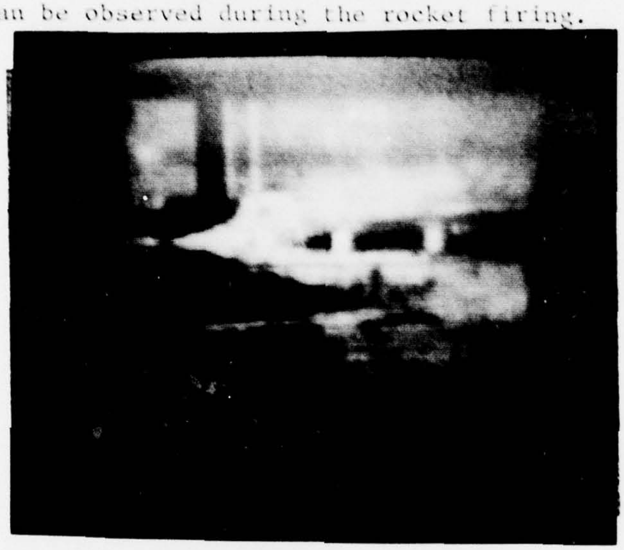

Fig. 11. Rocket plume test. Square targets are not obscured with ALFGL circuitry

D. Ground Applications

In ground applications targets are frequently obscured by hot backgrounds such as buildings, roads and runways. Figure 12A depicts FLIR imagery of a man target that is obscured while standing on a hot runway where the IR channels in the upper half of the scene contain ALFGL circuitry and those in the lower half of the scene contain standard common module circuitry. Figure 12B is the identical scene except that the man is standing in the upper portion containing the ALFGL circuits and is clearly recognized. Figure 13A is the FLIR imagery of a tree-sky, scene without ALFGL where the trees are saturated to white and the sky is suppressed to black. Figure 13B is the identical scene with ALFGL showing detail enhancement.

Fig. 12A. Man on a runway is obscured in the lower half of the scene without ALFGL

Fig. 12B. Man on a runway is seen in the upper half of the scene with ALFGL

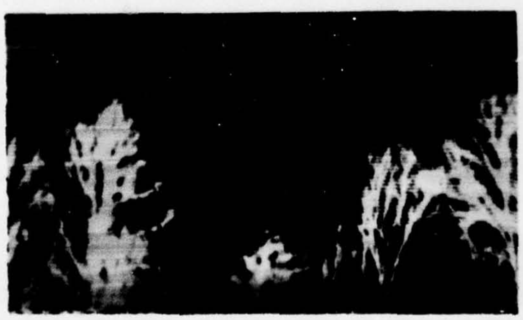

Fig. 13A. Trees and sky without ALFGL

Fig. 13B. Trees and sky with ALFGL

VI. ALFGL DEVELOPMENT

During 1975 an internal development program was initiated at the Night Vision Laboratory to design and fabricate the ALFGL circuitry. Demonstration of the first ALFGL circuit was held in June 1975 with 80 channels of circuitry designed into the common module M.O.D. FLIR system. Once circuit feasibility was demonstrated a contract was awarded to Circuit Technology Incorporated(4) to package the circuitry using thick film technology for airborne system flight testing. This circuitry provided 25 db of dynamic range expansion and operated over the temperature range of -54°C to +71°C. Common Module FLIR post amplifier boards are currently being redesigned to incorporate this ALFGL circuitry. These ALFGL post amplifier boards will be used in the Pilot Night Vision Sight and Target Acquisition Designator FLIR systems being designed for the Advanced Attack Helicopter. In 1977 a development contract was awarded to the Hughes Aircraft Corporation(5) to develop a low cost, monolithic integrated circuit version of ALFGL with 34 db of dynamic range expansion and automatic gain control for hands-off operation of the FLIR. This improved circuitry will be installed in all Army FLIR systems beginning FY81.

VII. CONCLUSIONS

The principal of Automatic Low Frequency Gain Limiting and its application to parallel scan FLIR systems has been described. ALFGL allows the system gain to be maximized without saturating the display. This enhances scene detail and improves the systems recognition capability. Field tests have demonstrated that 25 db of ALFGL dynamic range expansion is sufficient for airborne applications to eliminate horizon streaking and enhance terrain features. Tests have also demonstrated that the response time is adequate for missile tracking applications. Development efforts are currently being directed towards designing an ALFGL Circuit with 34 db of expansion which is required in some missile tracking applications and in scenarios containing fires. Automatic Gain Control will also be incorporated into the circuitry to provide hands-off capability to the FLIR.

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